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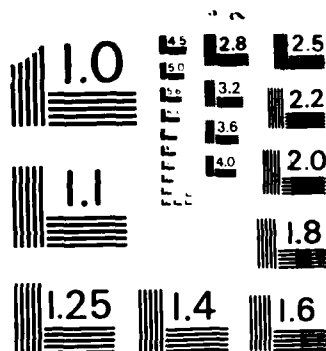
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FUNCTIONAL ASSESSMENT
OF
LASER IRRADIATION

ANNUAL PROGRESS REPORT 1982-83

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August 1982

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, MD 21701 -5012

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Maximum visual acuity and normal color vision are closely related to the integrity of an intact fovea. Exposure of the fovea to intense coherent light from a laser often produces severe and permanent structural changes in receptor function. Associated with this pathological damage are changes in the ability of the eye to resolve spatial detail under various contrast and wavelength conditions. In this report we have examined the immediate and long term changes in acuity associated with exposure to minimal diameter spots of Argon irradiation.		

TABLE OF CONTENTS

	<u>PAGE</u>
INTRODUCTION	1
METHODS	5
RESULTS	8
DISCUSSION	19
REFERENCES	22

LIST OF ILLUSTRATIONS

FIGURE 1	Optical System	6
FIGURE 2	Raw data recovery function	8
FIGURE 3	Baseline acuity changes with different contrast targets	9
FIGURE 4	Recovery functions for multiple Argon exposures ...	10
FIGURE 5	Effects of exposure power on the time course of the recovery process ...	11
FIGURE 6	Recovery functions for Argon exposures of different spot diameters on the retina ...	13
FIGURE 7	Effects of exposure duration on the time course of the recovery process ...	14
FIGURE 8	Repeated 2.0 mW exposures tested under three different contrast conditions ...	15
FIGURE 9	Average deficits at various times following exposure for various contrast targets ...	17
FIGURE 10	Preliminary data on the recovery process for exposures at various degree of eccentricity ...	18

INTRODUCTION

The original studies on the adverse effects of intense light on vision dealt with solar retinitis, sun-gazing during an elipse (Verhoff, Bell and Walker, 1916). Since these original and more casual observations of investigators in the early twentieth century, more analytic investigations with intense coherent as well as incoherent light have been directed toward understanding not only the threshold levels of irradiation (MPE) necessary to produce a permanent alteration in the visual system but also the physical mechanisms involved in producing such damage. In more recent years the threat of ocular damage has increased significantly as the result of the development of the laser. Prior to the development and employment of lasers the primary threat of light induced ocular hazards came from infrequent cases of solar retinitis or even less frequent cases of persons fixating on man-made sources such as a welder's arc, photocopiers and other bright light sources. The increasing applications of lasers in the military, in medicine, in industry and in the over-the-counter sales to the general public has been primarily responsible for the increased need for more comprehensive studies of the adverse effects of intense coherent light on the eye.

Ocular hazards associated with accidental or intentional retina exposures of humans and animals to intense laser light have traditionally been examined using ophthalmoscopic and morphological techniques. The energy levels involved in such exposures have often been quite intense and the durations of exposure short. These ophthalmoscopic and morphological techniques have produced varied results ranging from the demonstration of an observable retinal opacity to a

more subtle disturbance in the fine morphological appearance of the photoreceptor. While these techniques have demonstrated their sensitivity with respect to detecting thermal as well as mechanical damage mechanisms for exposures to intense light of short durations, they have not generally revealed the immediate or long term changes in vision associated with exposure to more moderate levels of laser light or to repeated exposures to relatively low level light. In these instances, actinic insult may be producing a series of alterations in the natural cyclic changes occurring within the retina to the point where the photoreceptor is no longer capable of carrying out its normal function within the system. These ophthalmoscopic and morphological techniques also provide little or no information about the degree or type of degradation in visual performance that can be expected from any observed physical damage. Changes in the ability of persons exposed to laser light to perform visually are of course of prime importance in missions where successful completion is dependent upon visually guided behavior. Furthermore, the liability of any organization for accidental laser exposure of an individual is ultimately determined by assessing the degree of disruption in vision experienced by the exposed individual. While morphological criteria have greatly contributed to the development of the ANSI guidelines, they may not be the most sensitive criteria to use since they are not generally sensitive to actinic insult and to subtle changes in visual performance.

The degree of degradation in vision associated with laser exposure is dependent upon a number of factors, both in terms of the parameters surrounding the type of laser exposure and in terms of the tasks used to assess the changes produced in vision. The behavioral effects of thermal and mechanical insult on the retina are, for example, immediate while those observed for more subtle photochemical reactions are slower to develop (Moon, Clarke, Ruffolo, Mueller and Ham,

1978; Robbins and Zwick, 1980). Intense exposures which produce immediately visible ophthalmoscopic lesions often also produce retinal bleeding and vitreous clouding which alters both scotopic and photopic vision regardless of the particular type of laser used or the site of the original exposure. Lesser intense, shorter duration exposures produce deficits in vision associated more with the parameters of the exposure. Foveal exposures produce changes in both color vision and in the fine resolution power of the eye while more peripheral exposures affect primarily peripheral and night vision. Longer duration exposures, regardless of their position on the retina, will produce more extensive damage as the beam is smeared across the retina and will cause changes in the spectral and resolution sensitivities of both photopic and scotopic systems. The wavelength of the exposure might also be expected to affect maximally those receptor processes tuned for the absorption of this particular wavelength, especially if the output power of the laser is at or near the threshold for eliciting change.

Early functional studies concerned with the adverse effects of intense light on the visual process were restricted to the evaluation of severe retinal morphological disruptions of the fovea in the rhesus (Tso, Robbins & Zimmerman, 1974; Weiskrantz and Cowey, 1967; Yarczower, Walbarsht, Calloway, Fligsten and Malcolm, 1966; and Graham and Farrer, 1969). The effects of these irradiation levels were usually permanent, producing impairment in visual acuity ranging from 40 to 80% of pre-exposure levels. Virtually no exploration of exposure levels at or below the transition from temporary to permanent visual losses had been conducted prior to this investigation, since no technique was available to expose an awake, task-oriented animal. The immediate acuity effects following intense irradiation are critical in the exploration of thresholds for functional disruptions. In previous studies, anesthesia was required for placement of retinal lesions, thereby elim-

inating the possibility of immediate postexposure acuity measurements for at least 24 hours. The inability to measure transient changes in visual acuity at threshold and subthreshold power levels, as well as a means to follow the initial phases of deficits elicited by suprathreshold power levels was a serious limitation in these previous studies dealing with a functional approach to laser safety.

The development of a behavioral exposure technique for evaluation of immediate consequences of laser exposure in the early phases of this contract has changed this situation (Robbins, Zwick and Holst, 1973). The technique involves the task orientation of the animal as a means of accurately placing laser energy on or just off the fovea. We have used such procedures to measure the effects of brief intense laser exposure on visual acuity for both temporary and more permanent kinds of visual function loss. In these experiments we have examined the effects of spatial and temporal parameters of laser exposure on transient visual acuity loss as well as the permanency of such effects. Furthermore, we have examined such effects on high and low contrast acuity targets and have used spectral acuity targets in determination of longer term effects.

In previous papers we have reported the immediate and long term changes in visual performance produced by relatively large diameter spots of laser light on the retina. The rationale for the use of large spots ($>300 \mu$) was to make the exposure conditions involved in our functional studies more compatible to those used in morphological and electrophysiological studies. Large diameter exposures have been used by some investigators to facilitate histopathological verification of changes in retinal morphology. Other investigators have used large diameter spots to both increase the probability of a foveal exposure and

to increase the magnitude of the change produced. The advantages, however, are largely procedural and do not represent the type of exposure condition likely to occur in the field to persons accidentally exposed to a laser beam some distance away. In the current report we have used only minimal diameter spots ($<50 \mu$). The immediate as well as long term changes in visual acuity measured against different chromatic backgrounds with different contrast acuity targets were examined for different power densities of Argon light below and up to the threshold for a permanent functional alteration.

METHODS

In previous reports and papers we have described a method to expose awake, task-oriented rhesus (Robbins, Zwick and Holst, 1973). This method will only be briefly described here. Visual acuity was measured using conventional black Landolt rings against achromatic (white) or chromatic backgrounds. Rhesus were trained to press a lever whenever a Landolt C was presented and not to respond when gapless rings of the same diameter were presented. If the subject failed to respond to a Landolt C during the 2 sec presentation, or if he responded to a gapless ring, he received a brief electric shock which was annoying but not highly painful or dangerous. Different schedules of reinforcement existed during training and testing and for false positive responding (lever pressing to gapless rings) and misses (failure to respond to Landolt C's). Landolt C's were randomly arranged within a series of equally-sized, gapless rings. All test targets were projected onto a rear projection screen by a standard carousel projector. A second projector served as a diffuse source of light when different contrast levels

were presented. Threshold acuity measurements were obtained by a tracking method which allowed the subject to adjust the size of the test object about his threshold. All testing was performed monocularly under photopic conditions. Chromatic backgrounds were equated for equal numbers of quanta.

A diagram of the optical system is presented in Figure 1. A 4 W Argon laser served as the light source. The diameter of the beam on the retina could be varied from greater than $300\ \mu$ when the expanding telescope and collimating lens were in the optical system to less than $50\ \mu$ when the lens assembly was removed.

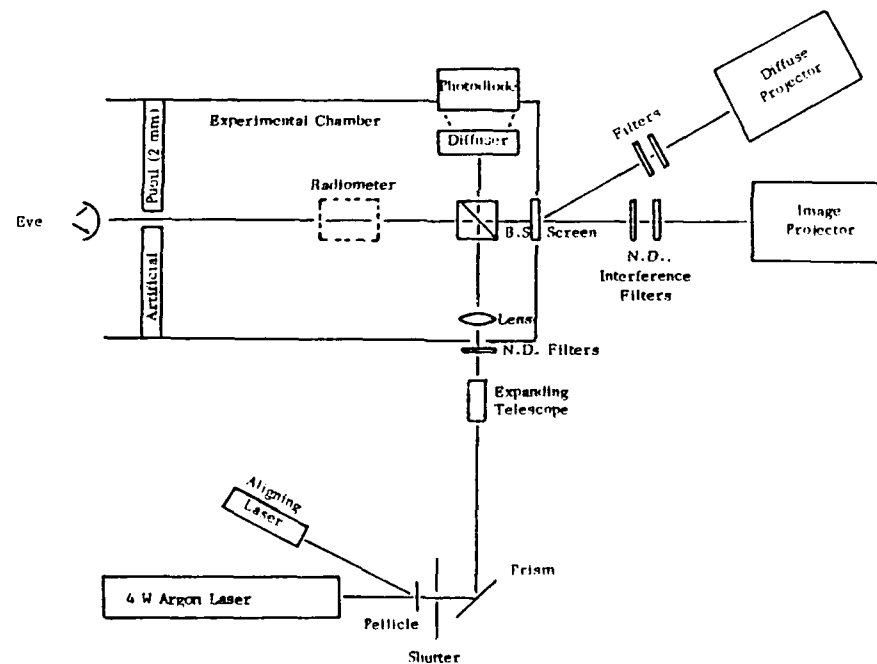


Figure 1. Optical system

The power density of the laser beam was controlled by the laser source itself and by neutral density filters placed in the optical pathway. The beam was aligned for on-axis exposures such that it was coaxial with a line between an

artificial pupil and the gap in a specified Landolt ring subtending less than 1 min of arc. The beam passed through a converging lens positioned such that the cornea was in the focal plane of the lens. When the animal was properly positioned, the beam entered the eye through the gap in a threshold Landolt ring and exposed the fovea; the area of the retina the animal was using to fixate on the critical feature of the discriminable target. All exposure durations and power densities were measured.

To assure proper orientation of the animal toward the screen, the animal's head was rigidly held in a fixed position during all behavioral testing. The animal was also fitted with an opaque facemask and monocular iris diaphragm. These restraints minimized the effects of small pupillary changes and lateral head or eye movements during testing since voluntary movements of any sort would block the animal's line of sight to the screen and result in the animal being shocked for incorrect detections. These procedures resulted in a high probability (>75%) that laser irradiation would produce a significant shift in maximum visual acuity. Shifts of the nature observed would imply foveal involvement since peripheral involvement only would not have produced any shift in maximum photopic acuity.

All exposures were 100 msec in duration. Such relatively short exposure durations were necessary to eliminate voluntary and involuntary eye movements away from the light. Exposures were triggered by the animal's correct detection of his threshold Landolt ring. Exposures were made over power levels from 0.3 mW to 3 mW measured at the cornea, beginning with the lowest power level. No more than one exposure was made per day and each power level was repeated a minimum of 4 times for each exposure and background (wavelength and contrast) condition. Exposures were made while the subject was viewing one of four different chromatic backgrounds at one of three different contrast levels. Immediately after exposure the recovery

of acuity was measured using achromatic and chromatic targets. If the subject failed to return to his pre-exposure acuity within the 2 hr session, further exposures on subsequent days were suspended and daily baseline measures of spectral and white light acuity were obtained. If or when recovery to baseline occurred, the animal was re-exposed at the point in the series where exposures were terminated.

RESULTS

Sample data of threshold acuity using the tracking technique is shown in Figure 2. In this particular session the subject was exposed to a 7 mW, 150 μ HeNe flash of 100 msec duration. Similar recovery functions were observed using minimal diameter spots of Argon but were not graphically represented in this manner because raw data is now automatically processed and stored in our computer rather than being displayed on a strip chart recorder. The occurrence of the exposure is indicated in the figure by an arrow. The ordinate indicates the

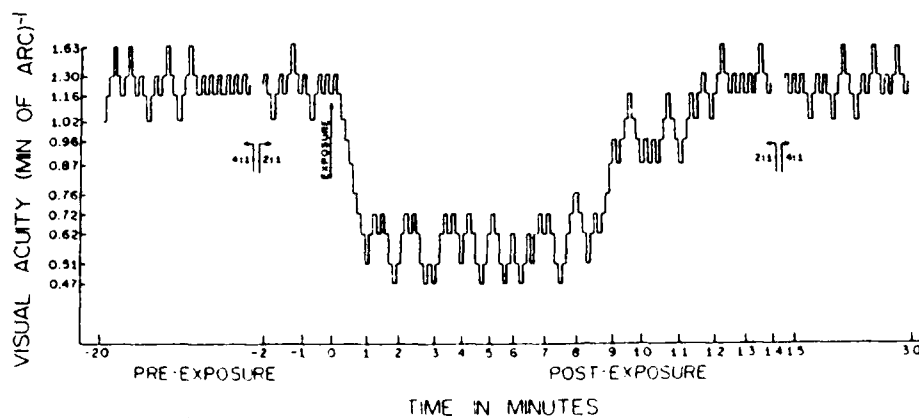


Figure 2 Raw data recovery function.

various sizes of gaps in presented Landolt rings and is plotted in reciprocal minutes of arc. Horizontal excursions of the chart represent the presentation of these targets. The abscissa represents corresponding times in minutes. The presentation of the gapless rings is indicated by vertical excursions between the horizontal excursions. The order of presentation of the slides in terms of their diameters was entirely dependent upon the animal's response on Landolt C trials. Incorrect detection of the Landolt C caused the recorder to plot downward and corresponded to the presentation of larger diameter rings.

The magnitude of the initial deficit in visual acuity following exposure was independent of exposure power or wavelength of the exposing source. Some small differences were observed with different diameter spots on the retina. The duration of the initial deficit as well as the total time required for full recovery was systematically related to the energy density of the exposure. As shown in the following figures, different test targets and backgrounds also affected the nature of the observed deficit and its recovery in time.

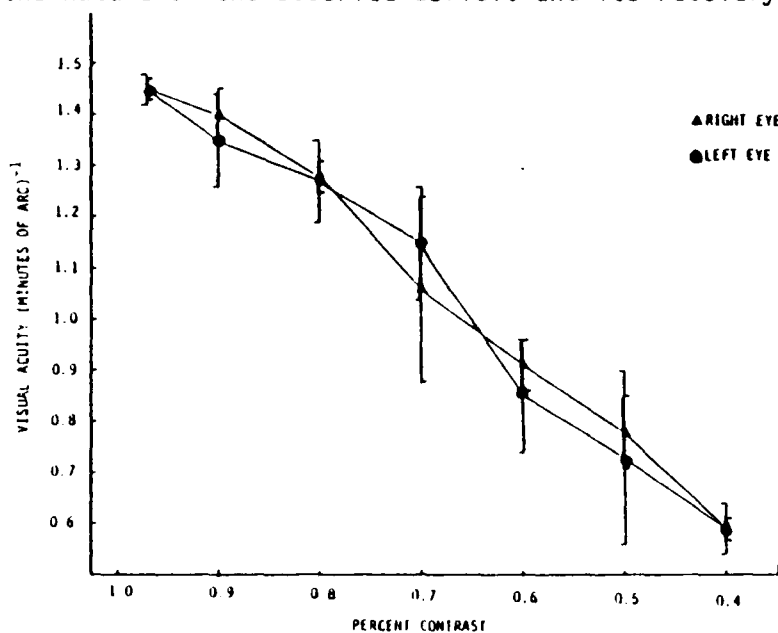


Figure 3 Baseline acuity changes with different contrast targets.

During the course of this effort we examined the effects that various changes in background viewing conditions had on the ability of the animal to resolve spatial detail and to recover from laser exposure. One condition which especially affected the animal's pre-exposure acuity was the contrast of the target against a bright background. Baseline changes in acuity with different contrast targets of equal background illuminance is shown in Figure 3 for one subject. Each data point represents at least five different session means. The background wavelength was 540 nm and similar functions were derived for other chromatic and achromatic backgrounds. Prior to exposure no significant differences existed between the experimental and control eye. At maximum contrast (97%) mean acuity was approximately $1.45 \text{ (min of arc)}^{-1}$ and dropped almost monotonically to approximately

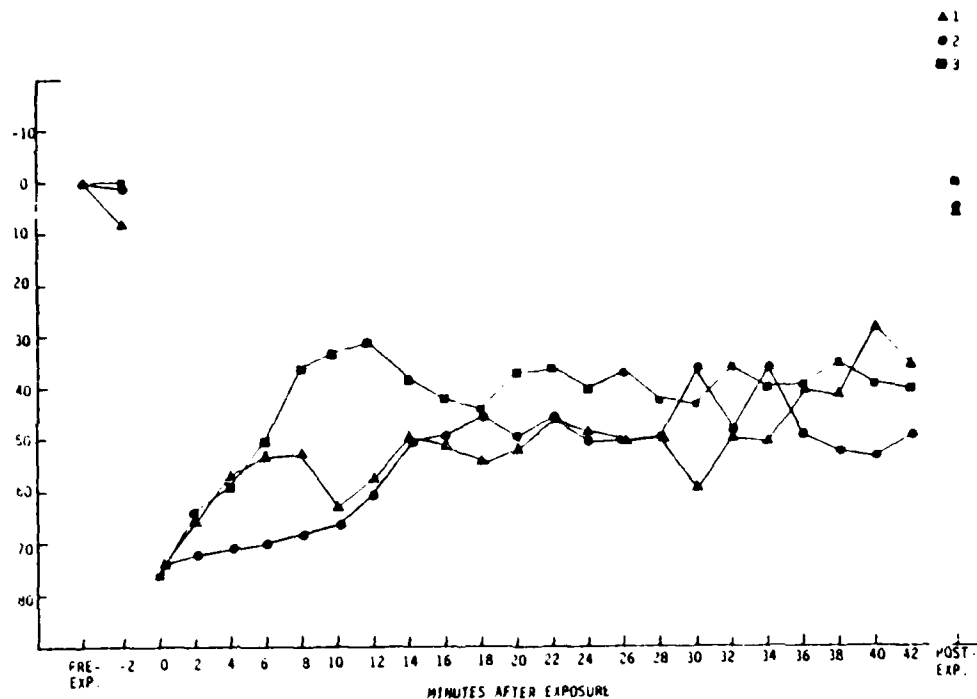


Figure 4 Recovery functions for multiple Argon exposures.

$0.55 \text{ (min of arc)}^{-1}$ when the lowest contrast targets were used (40%).

The effects of laser irradiation were measured using different wavelength and

contrast acuity targets. In Figure 4 the recovery from three separate Argon exposures to 2.0 mW, 100 msec flashes presented through the gap in a threshold Landolt C are shown. The background wavelength in this example was 540 nm and the contrast level was 90%. The three separate exposures were made over an eight day period. Each data point represents the running mean for each two minute period following exposure. In this figure the ordinate is plotted as a percentage of the deficit of the pre-exposure acuity level. Immediately following exposure the acuity level decreased to 80% of its pre-exposure level and remained depressed throughout the 42 minutes of postexposure testing. The following day the animal's acuity level had returned to its pre-exposure, baseline level.

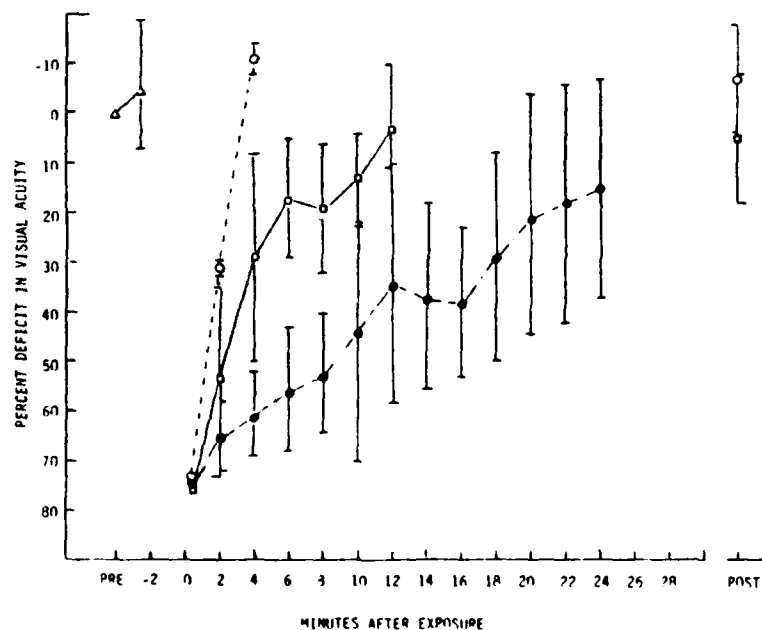


Figure 5 Effects of exposure power on the time course of the recovery process.

Changes in the power density of the exposure does significantly alter the time course for recovery at levels below that necessary to elicit a permanent functional alteration in acuity. No significant changes in the magnitude of the deficit, however, were noted for exposures of different energy levels. In Figure 5

the effects of two different power densities along with a sham exposure are shown for one animal tested with a maximum contrast (97%) white light background. The diameter of the spot on the retina was 323 microns and was positioned so that it was coaxial with a line between the artificial pupil and the gap in a specified Landolt ring. The two energy levels were 2.0 mW (squares) and 3.0 mW (dark circles). The open circles represent a condition where the animal did not receive any laser exposures but the projector was manually placed at the point corresponding to the deficit noted for the exposure and viewing conditions of the other two functions. The data points represent the mean recovery of at least four different exposure sessions; the vertical bars represent one standard deviation on either side of the mean. For the sham condition, the "recovery" represents the time it took for the projector to reverse direction and return to the pre-exposure level when an animal correctly detects all presented Landolt C's.

The magnitude of the initial deficit did vary somewhat when different diameter retinal exposures were made, although the effect was really quite small. Figure 6 shows the changes in the recovery functions observed in one animal for different diameter spots of Argon light. All exposures were of the same energy level (1.0 mW) at the cornea and were presented through a gap in a threshold Landolt C. The viewing conditions were identical. The total time course of the recovery also did not vary significantly with variations in the exposure diameter although here again larger diameter spots required a longer total recovery time than smaller diameter spots. Larger diameter spots presumably involved a wider area of the retina within the region of central fixation than did smaller diameter ones. At various times within the period of partial recovery, however, the diameter of the exposing beam proved to be a rather poor predictor of which exposure produced the largest percent deficit for that particular postexposure time period. In fact, the initial recovery to a minimal diameter spot (<50 μ) appeared the slowest although here again the difference was quite small and not statistically significant.

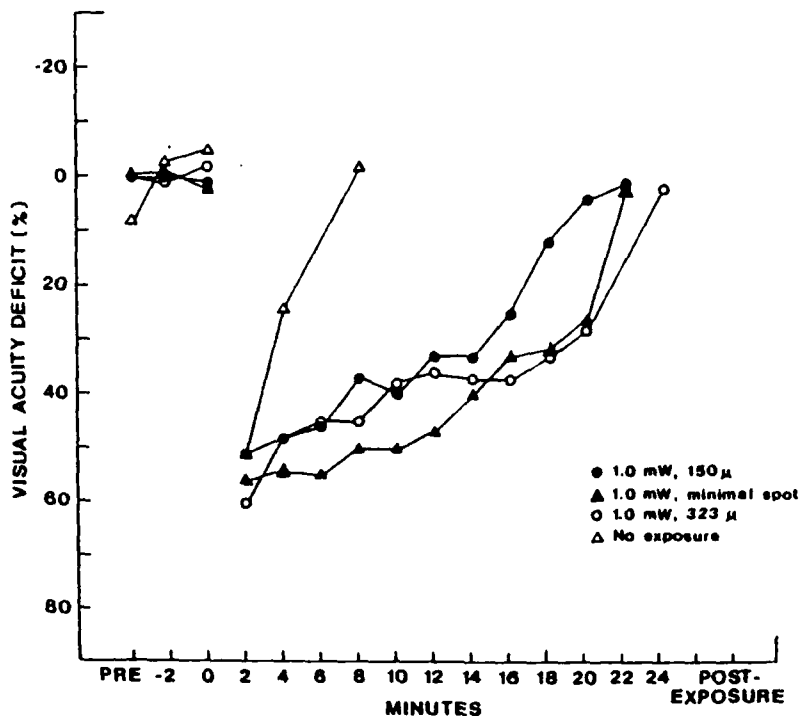


Figure 6 Recovery functions for Argon exposures of different spot diameters.

Some preliminary data was collected on what effects the duration of the exposure had on the magnitude and duration of the recovery process. In one animal exposures were made which varied in the total duration and in its distribution in time rather than energy or spatial extent across the retina. All exposures produced a minimal diameter spot on the central fovea. The energy level for the Argon exposures was well below that necessary to produce a permanent functional alteration. The target background was achromatic and high contrast targets were used to assess visual function. For single exposures of 50 msec or less (see Figure 7), the total duration of the recovery process was very rapid and even approached the lower time limit required for the computer and projector to reverse direction and present smaller and smaller test targets. In several cases where the projector was not manually reversed to the suspected acuity level for immediate postexposure sensitivity, some small deficits from

baseline acuity were noted but the recovery was so rapid we were unable to follow it with our program and test procedure. For longer duration exposures (>50 msec), the total time required for recovery was much slower requiring in the 103 msec example shown here, approximately 18 minutes to return to the pre-exposure baseline level. Two exposures of equal total duration and energy but not presented in immediate succession were not as effective as a single exposure of the twice the duration and total energy.

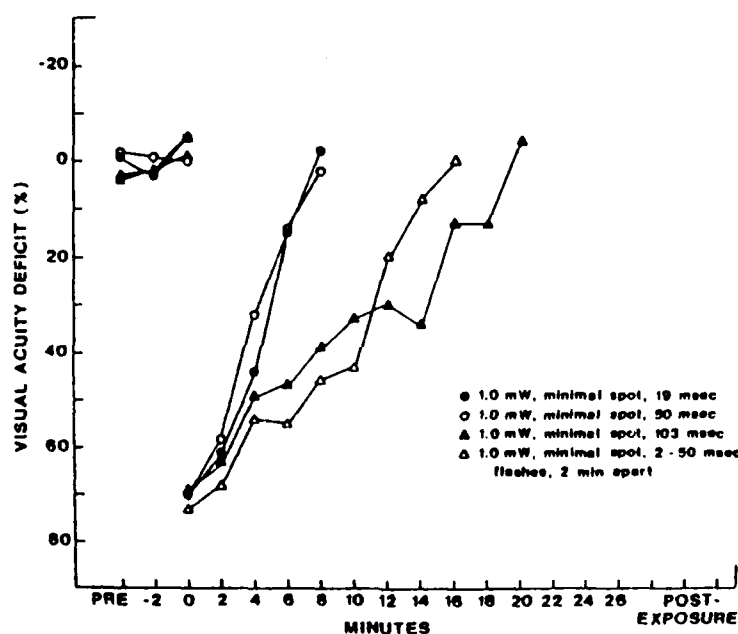


Figure 7 Effects of exposure duration on the time course of the recovery process.

The major part of the effort during this contract period has been and will continue to be to observe the changes in derived recovery to energies below and up to the point of threshold for a permanent effect when different background wavelengths and contrast levels are used to follow the process. We are still in the process of collecting the flash effects (below threshold) in three of our animals using these different viewing conditions. We can report that there are significant differences in the time course of the recovery process when using

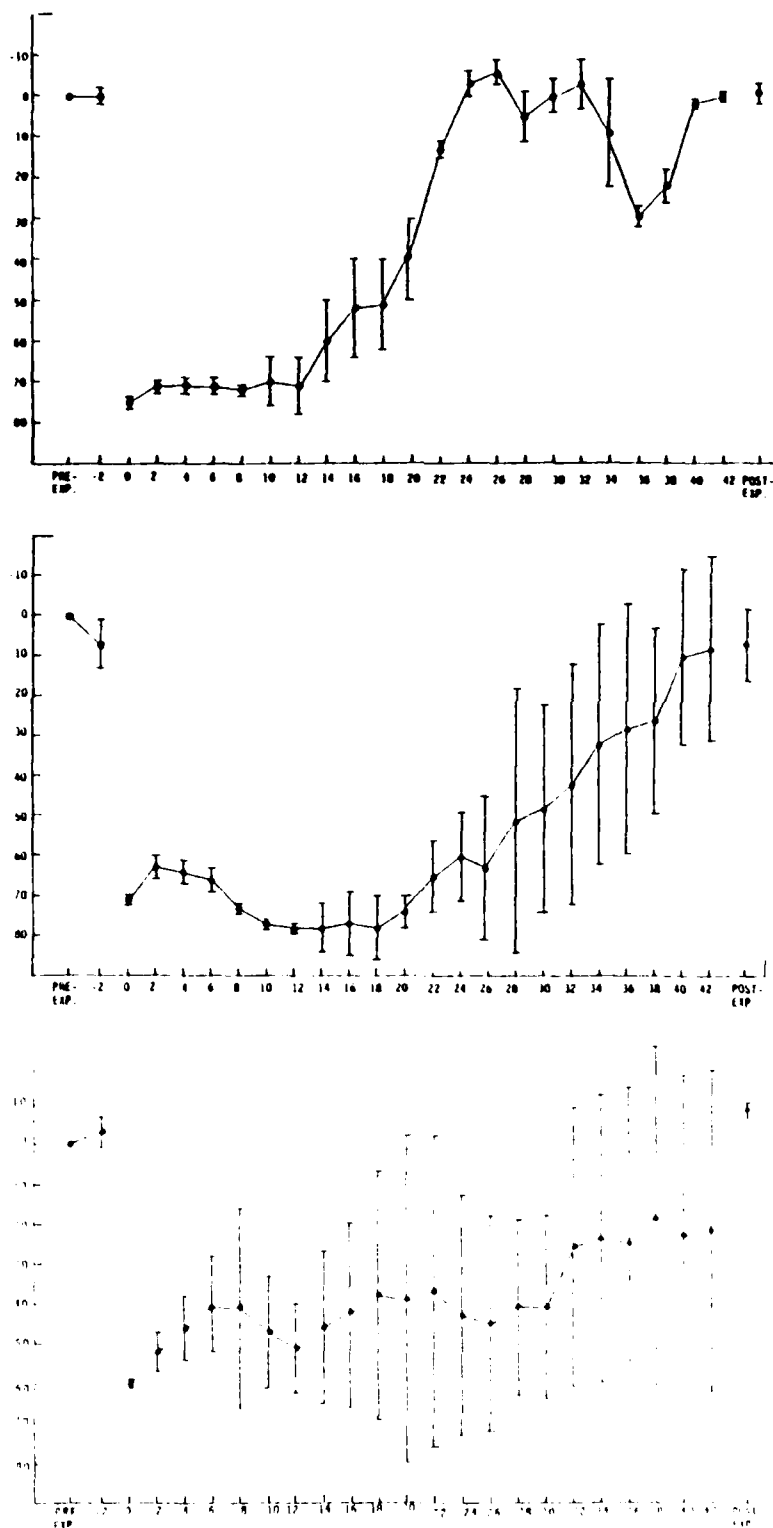


Figure 8 Repeated 2.0 mW exposures tested under three different contrast conditions.

different types of targets to assess visual sensitivity but these differences to date have not been systematic. That is, under some background wavelength conditions low contrast targets required a longer time for resolution at the pre-exposure level than did high contrast ones. But with other background wavelengths and the same laser exposure conditions (i.e., duration, energy, placement on the retina), high contrast targets took longer to resolve than low contrast ones. More data needs to be collected in this phase of the experiment before any definitive statements can be made about the specific effects laser irradiation has on the resolution of targets of different wavelengths and contrast. Data for one animal exposed to minimal diameter spots of Argon irradiation are shown in Figure 8. The energy of the exposure was 2.0 mW and the duration was 100 msec. In this particular example the background wavelength was 640 nm and the recovery functions plotted for three different contrast targets are shown: upper (90%), middle (70%) and lower graph (50%). In this case the exposure was most disruptive to high contrast targets and least to low contrast ones. Each data point in the figure represents the mean of 4 to 6 separate exposures. One trend has been observed and that is the variability within and between sessions for repeated exposures is greatest for low resolution targets. In this example total recovery time was longest for low contrast targets and shortest for high contrast ones. For other wavelengths this was not always true but then variability was quite high.

In Figure 9 the percentage of exposures producing various criterion deficits from their pre-exposure acuity level at selected times following exposure are shown for the three different contrast levels used in this experiment. All exposures were to minimal diameter spots of Argon light centered on the fovea by our fixation procedure. Data from 40 different exposures in one animal are summarized in this figure. In the upper bar graphs the percentage of exposures producing from 70 to 20% deficits in visual acuity during the first two minutes of postexposure testing are shown. The middle bar graphs show the percentage of

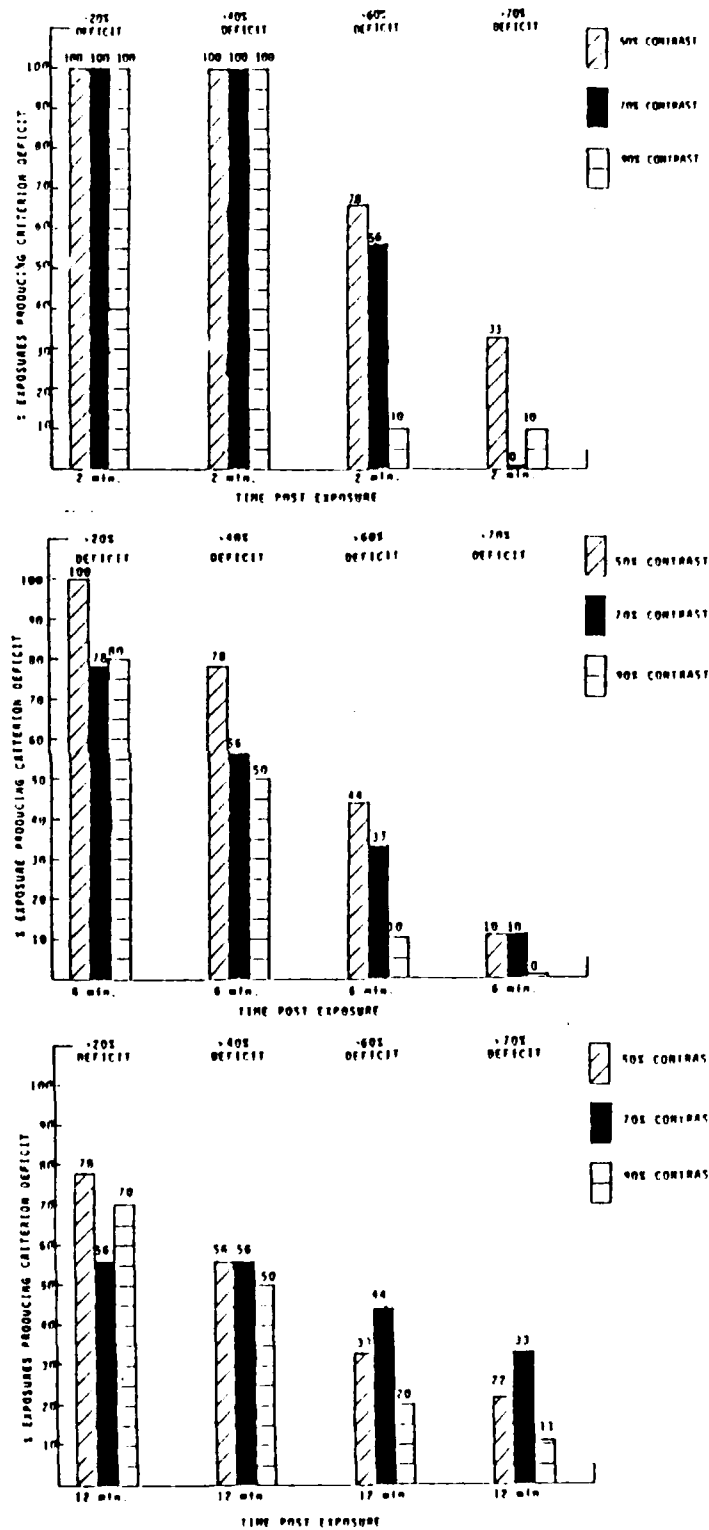


Figure 9 Average deficits at various times following exposure for various contrast targets.

exposures producing different deficits six minutes after exposure and in the lower bar graphs the percentage of exposures producing different deficits 12 minutes after exposure are shown. It would appear from this combined data that laser irradiation had its greatest effect on low (50%) contrast and least effect on high (90%) contrast targets especially during the early stages of the recovery process. These differences are small, however, and caution must be exercised when generalizing from this type of averaged data.

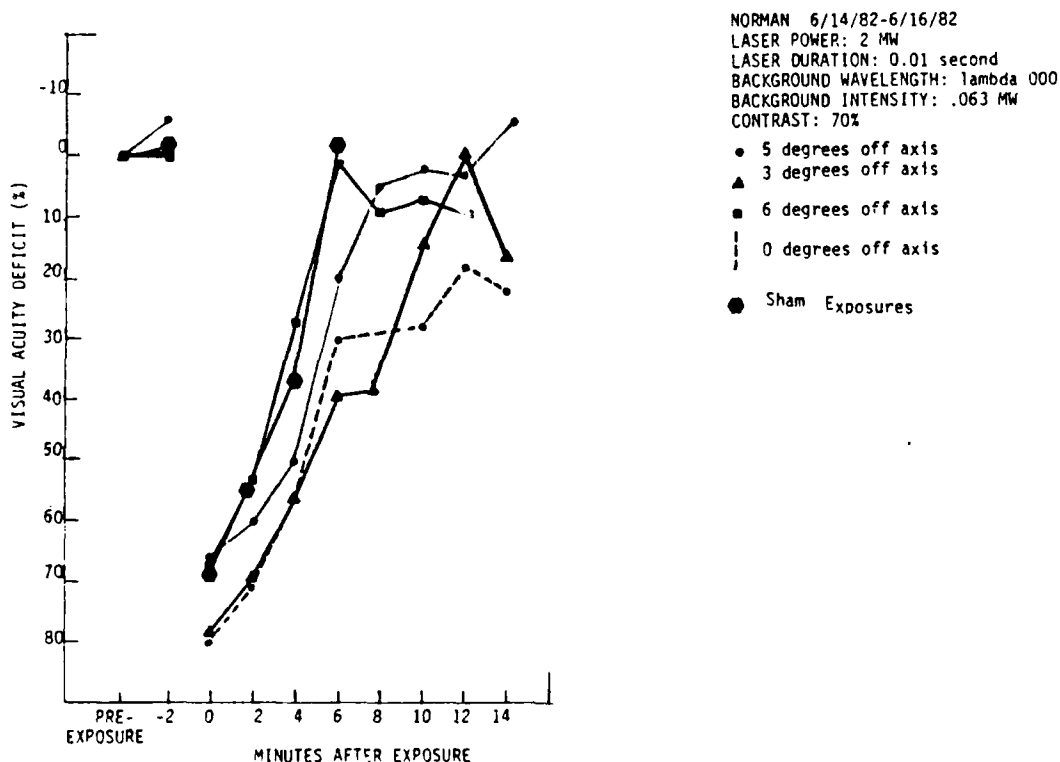


Figure 10. Recovery data for exposures at various degree of eccentricity.

Some preliminary off-axis exposures were made in one animal to low level Argon irradiation during the course of this project. Minimal diameter spots of laser light were positioned at 0, 3, 5 and 6 degrees from the point of central fixation; the gap in a specified Landolt C used during exposure. Immediate recovery was then followed using achromatic acuity targets of medium contrast

(70%). As the data in Figure 10 show, maximum deficits were larger and longer duration recovery needed for exposures centered on the point of fixation (0 and 3 degrees) and less for exposures away from this point.

DISCUSSION

Intense coherent irradiation of the eye not only seriously alters retinal morphology but also disrupts visual performance. If the exposure is of relatively short duration and centered on the fovea, both maximum visual acuity and normal color vision are adversely affected. If the exposure is off-axis somewhat and not centered directly on the fovea, less of a loss in photopic acuity is produced although peripheral and night vision might be equally altered. Such degradations in visual performance are important considerations for planning successful completion of visually guided missions by personnel who may become exposed to such intense laser irradiation, not to mention protection of the eyes of persons working around such devices.

In this report permanent functional alterations in the ability of rhesus monkeys to resolve detail under different spectral and contrast viewing conditions was examined following exposure to different output energies from an Argon laser. The threshold for a permanent alteration in the ability of animals to visually perform fine discriminations has been produced at corneal irradiances below those previously reported as being hazardous using gross fundusoscopic or fine histopathological criteria. This confirms our notion that changes in visual sensitivities may be more sensitive criteria for determining laser safety than the traditional structural ones.

The adverse effects of low level coherent irradiation appear selective

depending upon a number of conditions surrounding the type of exposure. Changes in the output power of lasers have little affect on the magnitude of the initial deficit so long as the exposure duration is relatively short (less than 100 msec) although such changes significantly alter the ability and time course of the visual system to recover. Changes in the diameter of the laser exposure on the retina as well as its relative position to the fovea does, however, affect both the magnitude and time course of the recovery process. Changes in the duration of the brief exposures also affect the recovery process and there is evidence for some degree of additivity over time of the adverse effects of coherent light on visual performance. The time course and degree of additivity remain unknown but nevertheless are important considerations in any determination of safety standards.

Chromatic acuity targets appear to be the most sensitive test for changes in visual function following irradiation especially when the exposures are placed on the fovea. Wavelength specific effects corresponding to the output wavelength of the exposing source have not, however, generally been found. Rather, the effects are generalized across the entire visible spectrum with maximum effects often at the spectral extremes. The contrast of the test target against either chromatic or achromatic backgrounds also affects the ability of animals to resolve spatial detail and the time course of the recovery following exposure.

The transitional point from temporary to permanent loss in visual acuity appears to be dependent upon the wavelength of the exposure source, the energy of the exposure, and the number of prior exposures at this and lower energy levels. Some long term repair mechanism must operate within the retina to aid in reversing any structural and actinic changes at the transition point. Animals exposed to progressively higher dosages of laser irradiation increase the time required for full recovery from normal photochemical (bleaching) time tables of minutes to

abnormally long delays of hours, days and even months. In several animals where acuity changes were produced and consistently maintained over days or months, recovery finally occurred without any visible residual effect.

These studies have demonstrated the usefulness of a functional analysis in determining safety criteria for intense coherent light as well as reflected on some the possible damage mechanisms which might be occurring within the retina. The functional approach might well be an important tool in making necessary modifications in the MPE and in delineating subtle structural changes which define the transition from temporary to permanent changes association with ocular hazards. Further research in this area is necessary to explore the exact dosage levels involved and to correlate this approach with other ophthalmological and morphological techniques.

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